general agreement with portions, at least, of the summarized statements have any reality, it may be inferred that appreciably less favorable conditions are probable in the near future, with noticeable upward trends beginning about 1930, reaching a maximum about 1950 to 1955, with the earlier date most favored as the center of the period, and with more severe conditions centering around the year 2050.

In conclusion, it is believed that the approximately correct long-period weather and fire sequences have been shown for California, their connections have been demonstrated in a cumulative sense, and the opinions prevalent concerning future prospects have been given, not as forecasts, but as the current thought on the data by competent students. Whether the picture "before" will prove to resemble the picture "after", or be something unexpectedly different, is uncertain. All we can confidently assert is that long-period secular swings take place and modify conditions over extensive time periods and areas, but individual years or series of years, and individual places, are subject to shorter sequences which by "interferences" make prediction uncertain as to definite turning points, places or conditions during any particular season.

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LONG-RANGE FORECASTS IN PUERTO RICO

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Reference to the tables of monthly surface-water temperatures of the Caribbean Sea and Florida Straits, 1920–32 emphasizes their close correlation with the surface air temperatures of windward coast stations in the area. A comparison of the annual temperatures for the period gives a positive coefficient of 0.88 for the San Juan-Caribbean Sea relation and 0.60 for Key West and the Straits. A comparable example is given by Pettersson (1), a coefficient of 0.86 being obtained for the air temperature of Madeira and the surface waters of the North Atlantic, 35 miles distant, based upon the years 1900–13. At San Juan the thermometric exposure is near the ocean at an elevation of 53 feet above sea level, the prevailing winds being easterly off the water. There occurs a lag in the yearly maximum temperature of both the air and water until the late summer or fall months. Another similarity is the maintenance of positive or negative trends with respect to the normal, for long periods. During the 35 years, 1899–1933, sequences of 14, 18, 19, 21, 22, 23 consecutive months appear in the mean monthly air temperature records, periods having the same temperature sign. This persistency is apparently due to a combination of factors, primarily the marine type of climate, and the position of the Island with respect to the North Atlantic high pressure area, with the continuity of circulation attendant upon it. The ocean currents, induced by the trades likewise play a part, the North Equatorial current dividing at the eastern end of the Antilles, forming the northerly current of the Bahamas and the southerly, flowing into the Caribbean. A correlation value of 0.82 was obtained for the temperature at San Juan and at Georgetown, Demerara, stations touching the north and south portions of the Equatorial current, respectively.

To trace, if practicable, the cause of the changes occurring at periodic intervals in the temperature trend with respect to the normal, comparison was made of the variations in wind direction between NE. and SE. at the station. This failed to indicate any definite influence on the corresponding temperatures, thus bearing out the statement of C. F. Brooks (2) that in the Tropics:

> The effect of change in wind velocity is most noticeable, while changes in direction are of little or no effect. When the trades are unusually strong for a period, the warm layer of surface water is driven forward and concentrated in the Equatorial current, where it forms a plus departure in temperature. The place of the warm surface sheet is taken by cooler subsurface water, making a minus departure.

C. E. P. Brooks (3) writing of the NE. and SE. trades, as these winds relate to the volume of the Gulf Stream, and later to the temperature of North Atlantic waters, has estimated the average rate of movement of the North Equatorial current at 17 miles per day, or the time required to flow between 16°N/23°W. and 16°N/60°W., a distance of 1,900 miles, at approximately 112 days. On this basis we may estimate the time to arrive at the eastern end of the Antilles as about 128 days, or 4 months. This being only the average rate, which would vary with the strength of the trades, a lowering of the figure by as much as 25 percent or a whole month would not be unusual in years when conditions favored. To obtain a value reflecting the monthly variation in the movement of the trades, mileage totals at the station of the NE., E. and SE. winds (constituting approximately 85 percent of the total movement) were used. These were then related to the variation in temperature of ensuing months, the results revealing that months of marked trades activity are generally followed by a decrease in temperature within 3 to 4 months. An excess of mileage did not in itself represent the control, unless the winds were of higher than normal velocity. In the summer and fall months, frequently, there occurred an excess mileage which only represented a steady trades circulation, to the exclusion of other directions, but with no exceptionally high velocities. At this season, too, the waters having been warmed to a greater depth, proportionately stronger winds become a requisite to induce a deep drift current, if temperature changes are to be effected. Such winds are generally lacking. The normal velocity of 15 miles per hour does not produce any marked disarrangement of the temperature gradient of the ocean (W. Ekman). Velocities in excess of this rate occur most frequently (80 percent of the total) in the months of November and December and January to April, a period of the year when the waters are warmed to the least depth. With this fact, it is not unexepcted to find a considerably higher correlation value resulting from the first and fourth quarter wind movement than in the second and third quarters (table 1). There is no indication, however, of a preliminary rise in temperature, mentioned by

Brooks (2) (3) with reference to temperatures of the Gulf Stream. A rise in temperature, when it occurs, is found to be related more directly to weak trades, and is generally accompanied by minus pressure departures. The negative deviation, on the other hand, follows increased trades and rising pressure, and is found to relate particularly to the winds of January to March, inclusive.

Correlation coefficients resulting from a comparison of the winds of this period and the temperature (and pressure) after a lag of 3, 6, 9, 12 months, and annual, follow (table 2). There is here noted a fairly close minus relation, most marked for the fourth quarter and the year. A value of −0.51 for the concurring quarter (January to March) suggests a time lapse of less than three months, but is more likely a reflection of the fourth-quarter trades control. After a lag of 12 months however there is a marked falling off in the probability. The

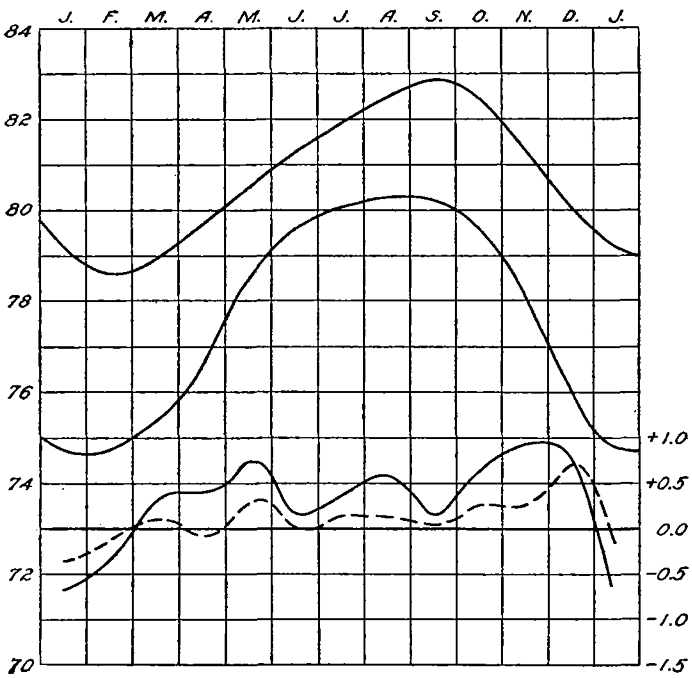

FIGURE 1.—Mean temperature curve of surface waters in Caribbean Sea (1) and air temperature at San Juan, P.R. (2) and deviations from the normal in 1930.

wind-pressure relation is expressed in a positive coefficient, somewhat smaller, but well-defined.

Variations in the temperature are not directly of great practical significance in Puerto Rico. The annual temperature of the Island varies between 70° and 80° F, with a deviation from the normal of seldom more than 3°. The rainfall variation, on the other hand, is most important to the agriculture of the section, owing to the high rate of evaporation and the consequent need for replenishment of moisture at frequent intervals. Only insofar as the temperature factor might be found to relate itself to the ensuing rainfall, is it thus of particular importance in long-range forecasts. Such relation, if existent, would also have an anterior trade-wind connection, based upon the latter's control of the temperature factor. As we find a certain positive correlation between the temperature of the late fall and winter months and the island rainfall, so too there occurs a negative though not so well defined relation between the January to March trades and the precipitation of the following year. The latter relation would take precedence in offering a six to nine months earlier indication. The temperature control, on the other hand, is found to yield somewhat more readily to correlation, and to further elaboration or limitation. Using the trade wind as a basis, however, there is shown an approximately 75 percent probability of the rainfall of the following year being of opposite departure sign. On this basis we may expect normal rains in the island in 1935, and the probability of a small deficiency in the current year, which latter has thus far been verified by the recent spring drought. In a quantitative correlation of the trades control, a coefficient of 0.48 is obtained with respect to the annual rainfall, or somewhat less than five times the probable error.

In using the temperature deviation as a basis, average departures at San Juan for the 5 months: October to February and for the 3 months: December to February were selected, the first or longer period average yielding slightly better values, both in the annual and seasonal relations, with the exception of the summer months. The 3 winter months give the same general relation, namely—a positive temperature deviation being followed by excess rainfall departures, and negative deviations by deficiencies, best indicated for the spring months and the annual period, with summer and autumn somewhat more variable (table 3). By eliminating all years of small-temperature deviations (below 0.5°), or conversely, including only the well-defined departures (of the winter period) there is a marked increase in the value of the indication, represented by a correlation coefficient of 0.78 in respect to the annual rainfall. There is thus a progressive relation, most consistent in years of well marked deviations, which may be expressed in terms of the approximate rainfall departure probable following certain temperature differences. Based upon the 35-year averages, a winter temperature deviation of 0.0° to 0.5° has been followed by an average departure in the annual rainfall of 1 inch or approximately normal; a deviation of 0.5° to 1.0° indicated a departure of approximately 5 inches or 8 percent, and any deviation of more than 1.0°, a departure in the annual rainfall amount by 9 inches, or 13 percent. Winter rains were omitted from the several correlations, except as a part of the annual. The rainfall at this season represents approximately 16 percent of the annual, being the least of the year. It also fails to yield any well-defined relation to preceding temperature values, one way or the other. A comparable instance of temperature-rainfall kinship is given by French (4) for Los Angeles and San Diego, California, where the temperature deviation for the month of March has indicated the following rainfall in 74 percent of the years of record at Los Angeles and 64 percent at San Diego. Relating the winter temperature deviation at San Juan and the Puerto Rico rainfall in like manner, a probability of 74 percent is obtained, or the same as at Los Angeles. Following a deviation of 0.5° or more, the probability is increased to 90 percent, or 15 years verification out of 17 years of record.

The cycle of the trades and ocean currents is an interesting one. Whether meteorological vagaries of abnormal years are caused by variations in the solar influence, it appears possible to trace certain types and persistencies more directly to the cycle of the trades. Thus we observe how a well-developed high pressure area in the North Atlantic initiates strong trade winds, which are followed by cooler ocean temperatures and currents that flow westward into the Gulf stream and eventually back to reinforce the area of Azores pressure for perhaps another cycle. And thus the weather of islands within the North Atlantic system of winds, including even parts of Europe may be determined to some extent, by conditions appar-

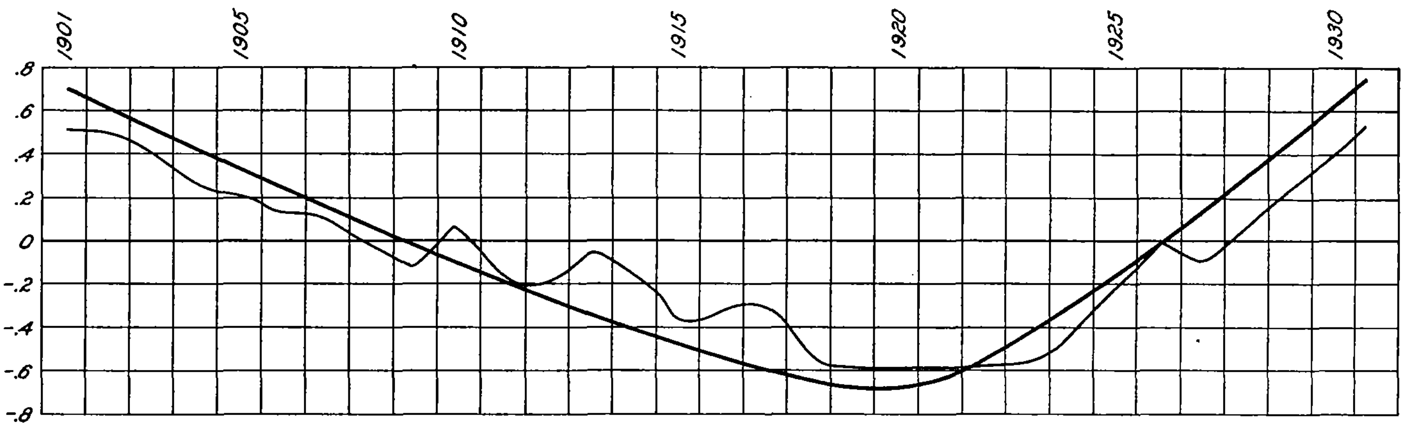

Figure 2.—Smoothed temperature departures, 1901, 1931, San Juan, P.R.

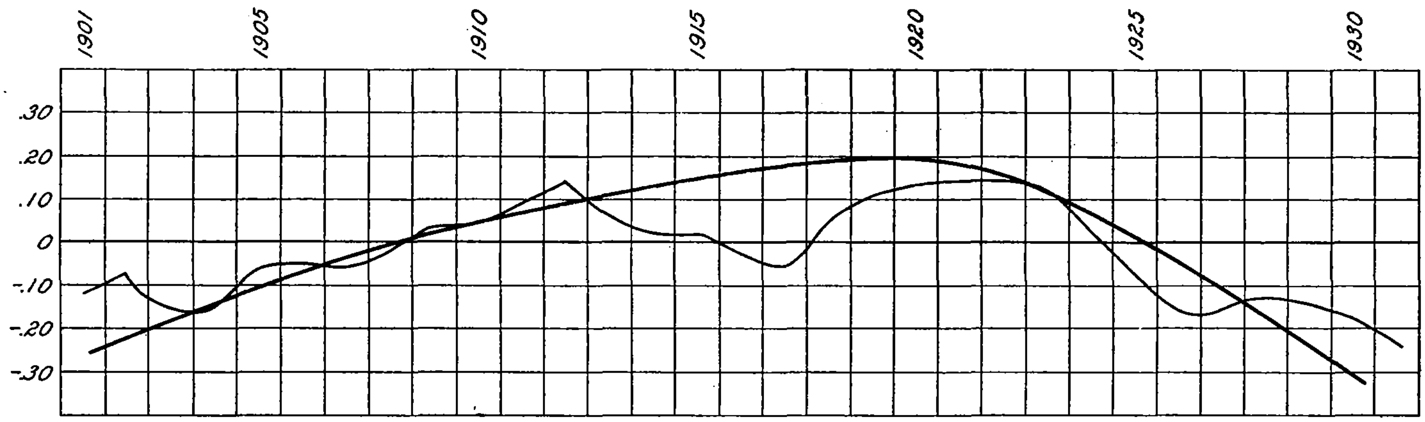

Figure 3.—Smoothed barometric departures (accumulated values) 1901-31, San Juan, P.R.

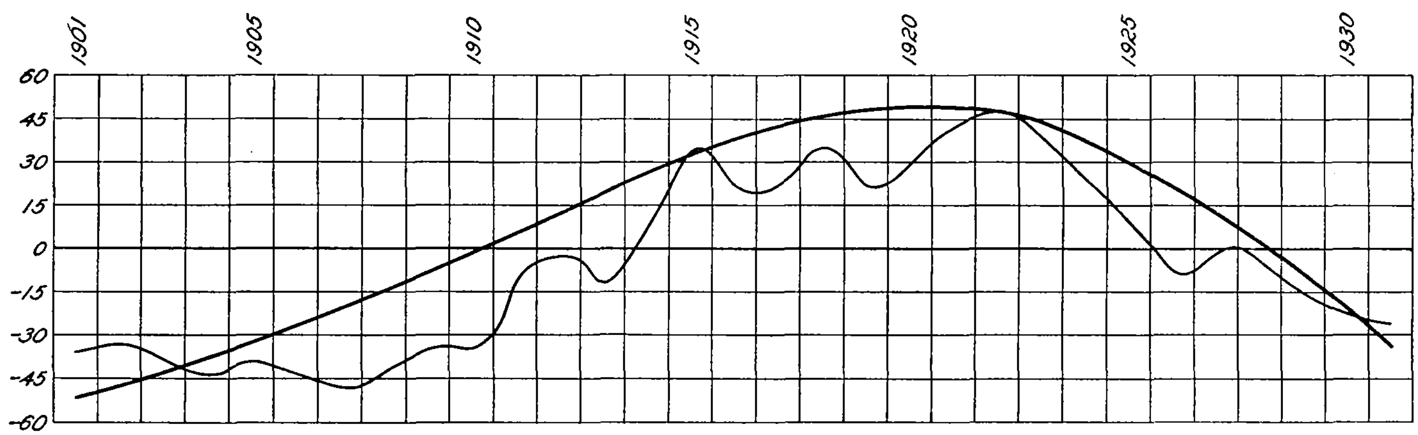

Figure 4.—Smoothed rainfall departures, 1901-31, Island of Puerto Rico.

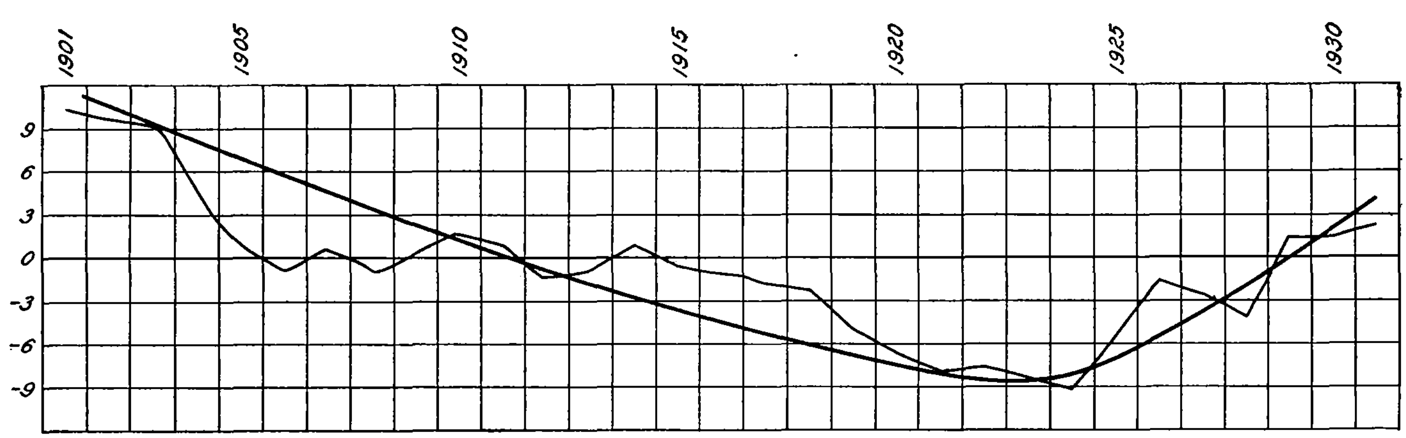

Figure 5.—Trade wind departures (smoothed) January to March, 1901-31, San Juan, P.R.

ent as early as 18 to 24 months previous. Pettersson (**1**) instances a definite relation between the ocean temperatures of the Atlantic and the rainfall of the following year in Ireland.

In Puerto Rico rainfall is partly convectional, partly the result of equatorial rains (in the south portion of the island, particularly), during periods when the Atlantic high-pressure area has shifted position or become weakened. Tropical storms play a smaller part owing to their comparative infrequency. Except as a factor in forced ascent in the highlands, the influence of the trades appears more generally as an inverse one. Heavy rains for the Island as a whole, are generally accompanied by relatively low pressure, subnormal trades, and positive temperature, departures. The interrelation of pressure, temperature and rainfall is shown in the charts of smoothed annual averages, figures 2, 3, and 4. The trend of the trades over the same period of years shows that from 1900 to 1913 winds were in general below the normal, from 1914 to 1924 being excessive, and from 1925 to date becoming deficient. The movement during January to March is shown in figure 5.

In the 35-year period, 1899–1933, the following extremes of monthly and annual temperatures occurred, at San Juan:

MINIMUM

1904	August.
1907	January, February, March.
1910	September.
1913	May, June, annual.
1917	January, February, October, December.
1921	July.
1922	April, November.
1925	February.

MAXIMUM

1901	April.
1902	February.
1903	January, June.
1905	November.
1911	November.
1914	December.
1915	October.
1931	March, May, July, annual.
1932	August, September.

The cool weather of 1904, which was more or less general, occurred during a period of poor solar transmissibility, due to volcanic dust (**5**). The deficiencies in 1907 were likewise of wide extent. In 1910 subnormal temperatures were persistent at San Juan until the last 2 months of the year, having had their inception in November 1909. Cool weather also prevailed in Havana in 1910, and on the continent, in Louisiana and in New England, and in 1909 in such widely separated sections as Minnesota and Hawaii. In 1913 temperatures were relatively cool in the Eastern Caribbean, and the annual deviation was the greatest in the 35-year period. Conditions were similar to 1910, though more pronounced, and the cool weather extended to Cuba, Louisiana, and to northern latitudes, in Minnesota and New England. In 1917 temperatures were again subnormal and cool weather occurred westward to Havana, and over much of the continent: Colorado, Louisiana, New England. It was a year of great sunspot activity, the maximum for 35 years. Beginning in 1916 annual temperatures at San Juan were continuously below normal until 1925, a 10-year period. During that time the average deviation was −0.6, with the greatest deficiencies occurring in 1917–18–21–22–23. The years 1918–24 are used by Blair in his study of mild winters on the continent, referring particularly to the Missouri Valley (**6**). During this period the North Atlantic high-pressure area was con-

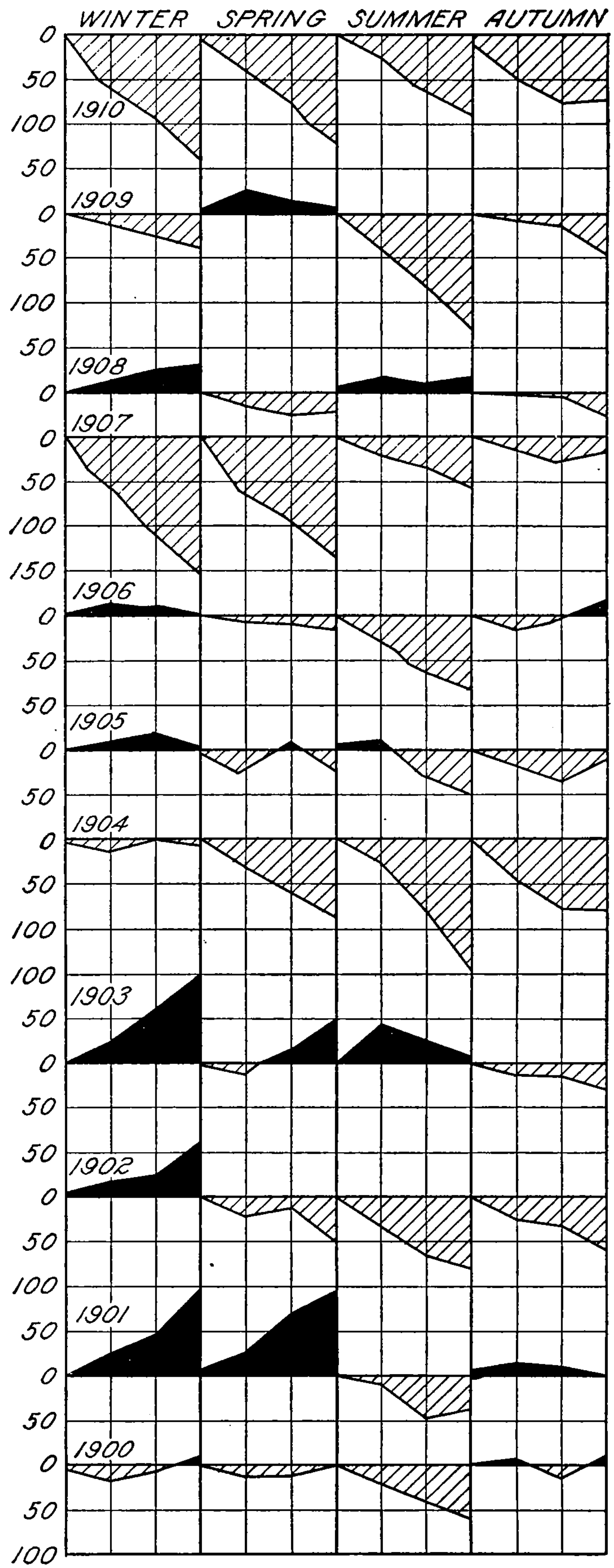

FIGURE 6.—Seasonal accumulated temperature departures, 1900–10, San Juan, P.R.

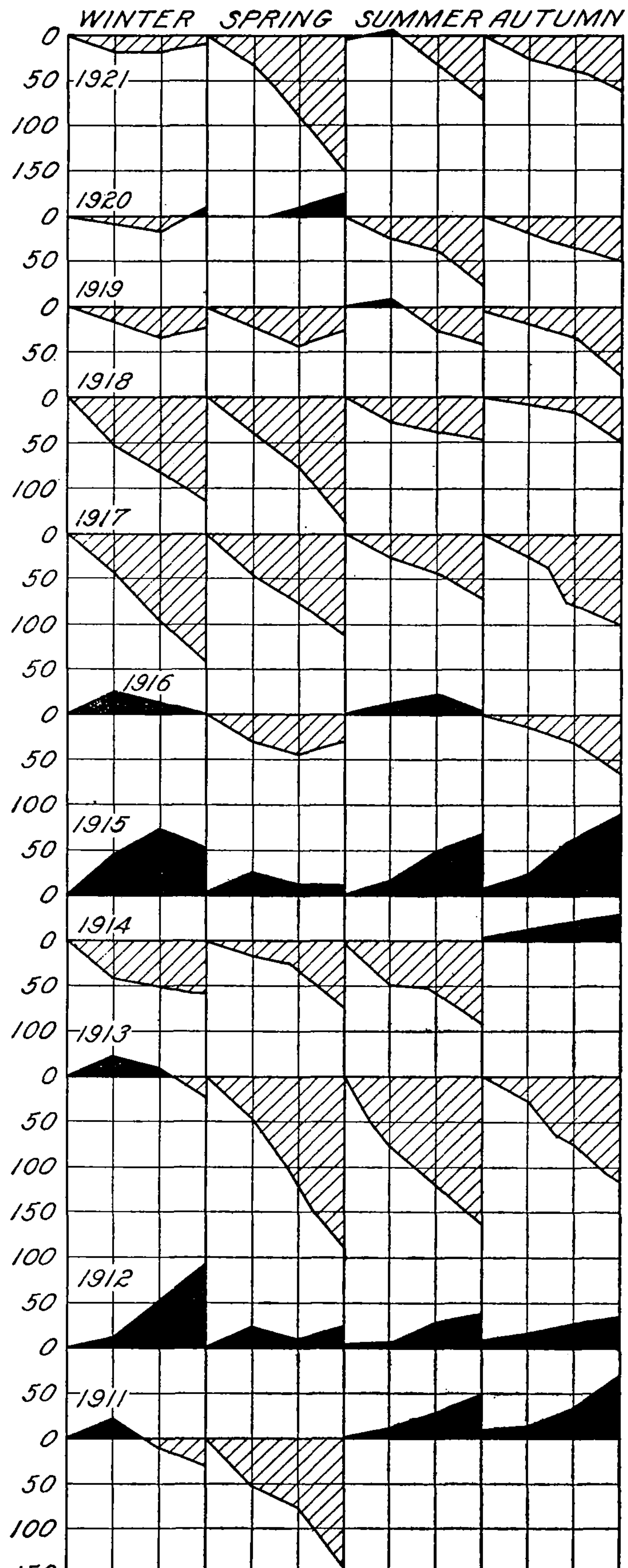

FIGURE 6.—Seasonal accumulated temperature departure, 1911-21, San Juan, P.R.

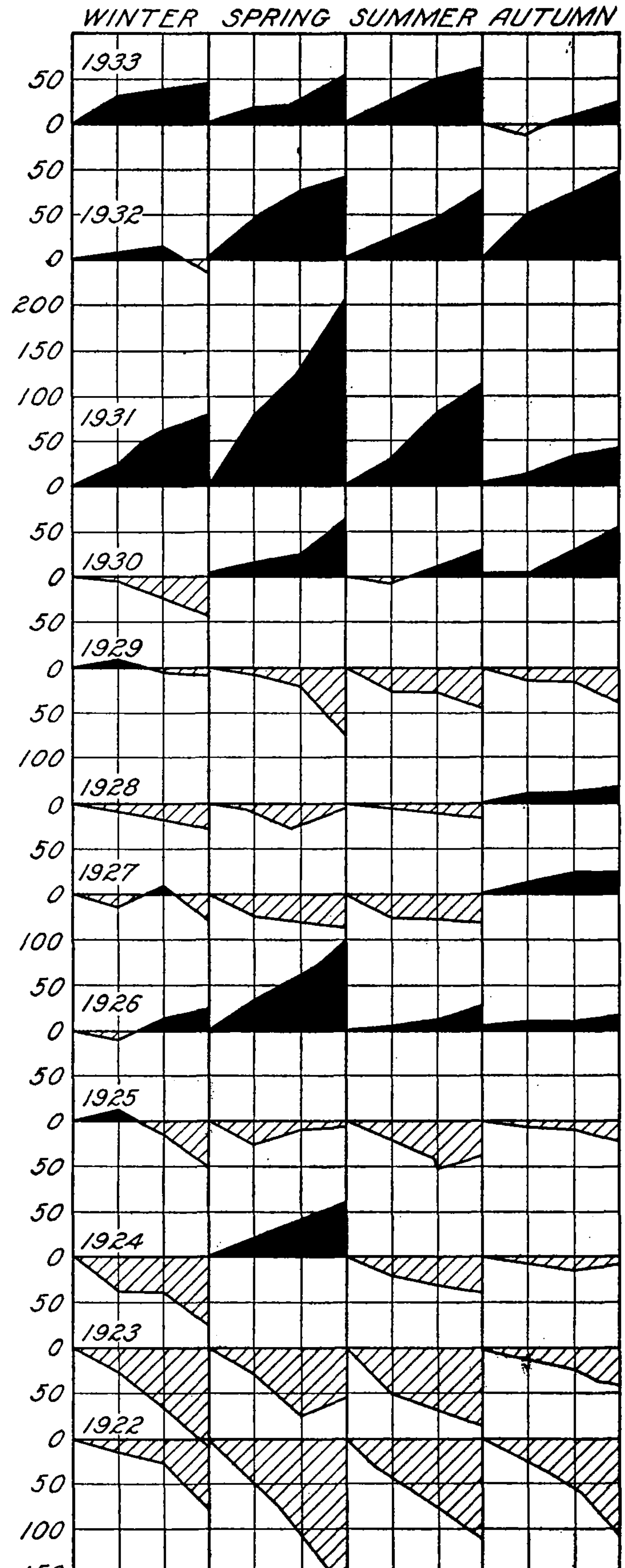

FIGURE 6.—Seasonal accumulated temperature departure, 1922-33, San Juan, P.R.

sistently above the normal. In an earlier group of years, cited by Blair, in which temperature deficiencies occurred on the continent, subnormal pressure prevailed over the Atlantic. Temperature data for this period at San Juan were not available. It is noted in this connection that an abnormal pressure distribution in the North Atlantic frequently produces opposite effects on the continent, as contrasted with the subtropics.

Excessive temperatures occurred at the station in 1901–2–3–5–15–31–32, in conjunction with pressure deficiencies. In 1901–03 and 1930–33 the positive departures in temperature occurred during periods of decreasing sunspot frequency—the year 1931 registering the largest temperature excess in 35 years. The solar influence is not always reflected however in the recorded temperature values, as exampled in the year 1913, when the extreme minimum annual temperature for 35 years coincided with the sunspot minimum. Referring to the years immediately preceding, 1910–11–12, which more nearly approximated the normal, Henry (**5**) states:

> The annual deviation of temperature for each of the years given, is of the same order of magnitude as that heretofore found and assigned to the sunspot influence, indicating, it seems to me, that in the ordinary run of years, those not characterized by an unusual number of areas or spots, the annual deviation of the mean annual temperature may be sufficiently uniform and of a magnitude that will satisfy the requirements of sunspot control.

The year 1913 was marked by abnormal pressure and wind movement in the North Atlantic. At San Juan the pressure from January to March 1913 averaged about 0.05 inch above the normal and the trades were 35 percent above the normal in the same period, in each instance being extreme deviations for the station.

Seasonal accumulated temperature departures for a series of years are shown in figure 6. Similar type graphs for six stations on the continent—Sacramento, Salt Lake, Denver, Kansas City, Cincinnati, and Washington, presented by Mattice, recently appeared in the MONTHLY WEATHER REVIEW (**7**). Comparison of the years 1920–1929, with the same period at San Juan, brings out the fact that what were mild years in the States (excepting 1920) were mostly subnormal in the Antilles. The winter trades were 10 percent above normal during the period.

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TABLE 1.—*Relation of quarterly trade-wind movement to temperature after a lag of 3 months. San Juan, P.R.*

	First quarter	Winds of second quarter	Third quarter	Fourth quarter
R	−0.62	−0.23	−0.29	−0.52
E	.104	.110	.107	.084
R/E	8.5	2.1	2.7	6.2

TABLE 2.—*Relation of January to March trade-winds to temperature after a lag of 3, 6, 9, 12, months, and annual*

	Following a lag of months				
	3	6	9	12	Annual
R	−0.62	−0.61	−0.74	−0.27	−0.73
E	.073	.074	.059	.130	.055
R/E	8.5	8.2	12.5	2.1	13.1
	To pressure				
R	+0.35	+0.37	+0.31	+0.37	+0.57

TABLE 3.—*Relation of winter temperature at San Juan to island rainfall of following season and annual*

	Spring	Summer	Autumn	Annual
R	+0.40	+0.33	+0.33	+0.55
E	.096	.103	.104	.082
R/E	4.26	3.20	3.08	6.71
	Temperature: October to February (5-month average) to rainfall of following season, and annual			
R	+0.54	+0.28	+0.39	+0.63
	Winter temperature deviation of 0.5 or more to rainfall of following season, and annual			
R	+0.56	+0.35	+0.45	+0.78